United States Department of the Interior, Oscar L. Chapman, Secretary
Fish and Wildlife Service, Albert M. Day, Director

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A FISHWAY THAT SHAD ASCEND

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PREFACE

This report is the result of one of several studies being made to obtain basic information required for the design of fish-ways that will successfully pass shad.

The catch of shad along the Atlantic Coast has fallen from some 50 million pounds in 1896 to about 14 million pounds in 1946. Thus, within a period of 50 years the catch declined to less than 30 percent of its former size and because of this continued decline, the Atlantic States Marine Fisheries Commission sponsored legislation authorizing funds for a six year study of shad along the Atlantic Coast. (Public Law 249, 81st Congress). These studies will provide the Commission with information which will enable it and its member states to restore the shad fisheries to a greater and more stable yield.

Although the causes for the decline in the shad fishery are many, one of the most prominent factors has been the construction of numerous dams which prevent shad from reaching their native spawning grounds. Many of the dams had fishways but, unfortunately, they were poorly designed and ineffective. Recently, however, the numbers of shad consistently observed ascending the Bonneville fishways on the Columbia River and a fishway at Lawrence, Massachusetts demonstrate that shad will use fishways if the proper hydraulic conditions exist. As a part of our shad program, we must define those hydraulic conditions.

Much of the information contained in this report was obtained through the interested cooperation of the Massachusetts Department of Conservation and especially Mr. Francis Sargent, Director, Division of Marine Fisheries, and Mr. John Burns, Supervisor of Fishways. Mr. Ernest Barnes, a former aquatic biologist with the Massachusetts Department of Conservation, and Mr. Howard Dobransk, Essex Company, Lawrence, Massachusetts, have supplied particularly valuable information on the movement of shad in the fishway, and Mr. Harry Goodwin, regional supervisor, Office of River Basin Studies, Fish and Wildlife Service, has given valuable advice on many occasions. The shad investigations are under the immediate supervision of Mr. Gerald B. Talbot.

Clinton E. Atkinson
Chief, Middle and South Atlantic
Fishery Investigations
Fish and Wildlife Service

April 18, 1951

INTRODUCTION

One of the serious problems confronting the conservation authorities responsible for protecting and developing shad fisheries is the construction of satisfactory fishways. The reluctance of shad to enter and to ascend most fish ladders has usually resulted in the shad being completely cut off from all of the natural spawning areas above the first dam encountered in their upstream migration. The passage of shad through the fishways at Bonneville Dam on the Columbia River is a notable exception, although even in the fishways at Bonneville Dam the shad are not always successful in ascending[1]. However, it is difficult to find in the enormous fishway system at Bonneville, with its pools 40 feet in width, its auxiliary water supplies and its huge collecting system, a solution to the problem which would be applicable to the smaller, privately owned dams with which those interested in shad fisheries on the Atlantic Coast are largely concerned. Another fishway, not very well known, which shad ascend successfully is the fishway at the Essex Company Dam on the Merrimack River at Lawrence, Mass. For the consideration of those concerned with the design of suitable fishways for shad the distinctive features of the fishway, reputed to be the only fishway on the East Coast successfully passing shad, are outlined here.

HISTORY AND DESCRIPTION OF FISHWAY

The fishway at the Essex Company Dam in Lawrence was built in 1919 at a cost of $28,000. Because several previous fishways had been destroyed by ice the fishway was heavily constructed and located in its present position so as to have a minimum of exposure. The fishway has a total of 47 pools to overcome a maximum difference in elevation of 30 ft. between the forebay and tailwater. The lower 36 pools are 8 ft. by 8 ft. and are arranged in pairs (Figure 1). There is a drop of 0.6 ft. between pools (Figure 2) although when the fishway is in operation some of this difference is taken up by the slope of the water in the pools so that the actual difference at the weirs is only about 0.4 ft. The weirs are notched and are unusually thick (1 ft.). The fishway narrows at the top into single pools which are only 6.3 ft. wide but are approximately 10 ft. in length. The upper 9 pools have adjustable plank weirs to accommodate the fishway to fluctuations in forebay level.

1/ "Passage of Fish over Bonneville Dam" Annual Report, Corps of Engineers, U. S. Army, 1949.

The entrance to the fishway is 4 ft. in width and is located at the edge of one of the main channels (Figure 3). In a normal year the new wood used for flashboards on the crest of the dam is placed on the north side of the dam. During the winter the weaker boards on the south side of the dam frequently become damaged by ice and are washed out so that in the spring the flow is concentrated in the channel next to the fishway entrance. Large curved reinforcements on each side of the entrance (Figure 1), probably designed to strengthen the fishway structure at the opening, may actually be responsible for a large measure of the fishway's success with shad.

In 1936, the fishway was severely damaged by flood waters. The following year major repairs were undertaken and at the same time several modifications were made. The most important of these changes was an alteration of the weirs. In crossing the original weirs which were 4 ft. wide (Figures 1 and 2), the deep-bodied shad sometimes had difficulty because of the relative shallowness of the water (from 2 in. to 6 in. in depth). Fish examined in the upper part of the fishway were frequently found to be badly scraped. To remedy this condition, in 1937 notched weirs were constructed on top of the original weirs. Each of the notches (Figure 11) is 2 ft. wide at the top, 1 ft. wide at the bottom and 1 ft. deep. The floor of each notch is sloped at an angle of 30°. The top of the notched weir is 1.5 ft. above the original weir. This modification not only resulted in a deeper flow across the weir but it raised the average depth of the water in the pools when the fishway was in operation from less than 3 ft. to more than 4 ft.

Because the shad did not enter the fishway under high tailwater conditions (tailwater elevations of 15 ft. above mean sea level or greater) in 1937 an opening was cut in the side of one of the lower pools (Figures 4 and 9) to allow the fish to enter the fishway without passing through the turbulent area (Figure 7) near the entrance.2/ Another change that was made in 1937 was the replacement of the adjustable plank weirs in the lower 3 pools ("flashboards" of Figure 2) with notched concrete weirs.

THE SHAD RUN AT LAWRENCE

At the present only the lower 27 miles of the Merrimack River, heavily polluted with industrial wastes and sewage, are available as spawning areas for shad.

2/ There is no evidence that the shad have ever used this opening.

The Lowell Dam, nine miles above the Essex Company Dam at Lawrence, has proved to be an impassable barrier. Although shad have been observed in the pools below the dam at Lowell none have been observed in the Lowell Fishway 3/ or above the dam.

Regarding the passage of shad through the fishway at Lawrence, the Annual Report of the Division of Marine Fisheries, Mass. Conservation Dept., June 30, 1944, states:

> "As partial answer to the oft-made inquiry whether shad will ascend a fishway, our Biologist reports that early in July, 1943 the flow of water was shut off in the fishway at Lawrence (Merrimack River) and after the water had quieted, shad were observed in the ladder pools from the bottom up to the 37th. pocket. From there on there is a short straight run into the pond above the dam. One of these shad measuring 15 inches was brought into the Division Office for display. These fish had the characteristics of the Connecticut River Shad and might have been from the planting of fry from Connecticut in 1935."

At the same time that the shad use the Lawrence fishway there is a large run of alewives and the shad have frequently been observed to follow the alewives, which are more aggressive, into the fishway. Shad, however, do not enter the Lawrence fishway under all water conditions. The probable minimum water level at which shad enter the fishway 4/ is at a tailwater elevation of 11 ft. (above mean sea level). At this level the first weir is completely submerged and the water flows through the entrance at a velocity of about 2.6 ft/sec.

3/ The Lowell fishway was also designed in 1918 by the same engineer who designed the fishway at Lawrence. It is, however, an entirely different type of fishway.

4/ The notes on the behavior of shad in the Lawrence fishway, the tailwater conditions at the time of entry, the numbers of fish, etc. are based on the observations of Mr. Ernest W. Barnes, former Biologist for Mass. Conservation Dept., Mr. John Burns, Supervisor of Fishways for the Mass. Conservation Dept. and Mr. Harold Dobransk, Gate Operator for the Essex Company in Lawrence, Mass. who is in charge of the operation of the fishway.

The probable maximum water level at which shad enter is at a tailwater elevation of 14.5 ft. (above mean sea level). At this water level the velocity of the water through the entrance is reduced to about 0.3 ft./sec. and water flows through the opening in the wall of the second pool at about 1 ft/sec. Above this tailwater level the water in the vicinity of the fishway entrance becomes excessively turbulent (Figure 6).

Estimates of the number of shad annually ascending the ladder at Lawrence range from 1,500 to more than 3,000. The size of the total shad run in the Merrimack River is difficult to estimate. In 1946 a catch of 75,000 pounds of shad in Newburyport harbor was reported. However, commercial shad fishing at the mouth of the river is sporadic and in some years the Merrimack is not fished commercially at all.

MODEL STUDY

In order to examine in detail the characteristics of flow in the Lawrence fishway under varied water conditions, a plastic model of the lower six pools (Figure 13) was constructed and installed at the Alden Hydraulic Laboratory, Worcester Polytechnic Institute. The model was built according to the original plans (Figures 1 and 2) with removable inserts for the later modifications. Patterns of flow were studied by the addition of dye to the water.

A comparison was made of the flow patterns in the fishway pools with the two different types of weirs, the original wide weir and the notched weir with its sloping floor. The direction of the main flow (Figure 12) was approximately the same with both types of weirs, although the flow from the notched weir was much more concentrated. The greater depths created by the addition of notched weirs resulted generally in lower velocities and reduced turbulence, particularly in the lower areas of the pools. However, the maximum velocities in the jet produced by the notched weir were about 0.8 ft/sec. higher than the maximum velocities produced by the wide weir. Thus, with the notched weir, there was a much sharper contrast between the velocity of the water in the jet and the velocity of the rest of the water in the pool. With the broad weir and the shallower depth, velocities throughout the pool were more uniform. The condition at the approximately 180° change in the direction of flow in certain pools (Figure 12) is probably accentuated by the concentrated flow from the notched weirs.

The characteristics of flow in the fishway entrance and in the lowest two pools [5] were studied under a variety of tailwater conditions (Figures 13, 14, 15). Flow patterns made with both the original "flashboard" arrangement (Figure 2) and with the notched weirs installed in 1937 showed only minor differences because the weirs are flooded throughout most of the range of tailwater elevations at which shad enter the fishway. The flow in the lowest pool and through the entrance was remarkably uniform and lacking in turbulence. Velocities through the entrance ranged from a maximum of 2.6 ft/sec. at a tailwater elevation 11 ft. (above mean sea level) to less than 0.5 ft/sec. at a tailwater elevation of 14.5 ft. (above mean sea level). The large curved reinforcements on each side of the entrance created an area with lower velocities just outside the entrance (Figures 13, 14, 15).

SUMMARY

There are a number of distinctive features of the fishway at Lawrence and it is difficult to know which of these features are responsible for the success of the fishway in passing shad. The location of the entrance certainly must play an important role. The rounded form of the entrance itself and its position relative to the direction of stream flow may also be critical factors. Equally significant may be the low velocities (average 1 ft/sec.) and the lack of turbulence with which the water flows through the entrance. There is no "jump" at the entrance at the water levels existing when shad enter the fishway and thus, the fish are completely in the fishway before any special effort to ascend is required. The size of the pools may be important and the fact that the pools are usually shaded by the high walls should also be considered. The rise from one pool to another is not great and the relatively small volume of flow (approximately 10 cubic feet per second) produces less turbulence than found in most fishways.

[5] The opening in the side of the second pool (Figure 9) was not made in the model. It is not involved at tailwater elevations of 13 ft. (above mean sea level) or lower and it has very little influence upon the pattern of flow until tailwater elevations exceed 13.5 ft. (above mean sea level). Its main effect is a reduction in the velocity of the flow through the fishway entrance.

D A T A

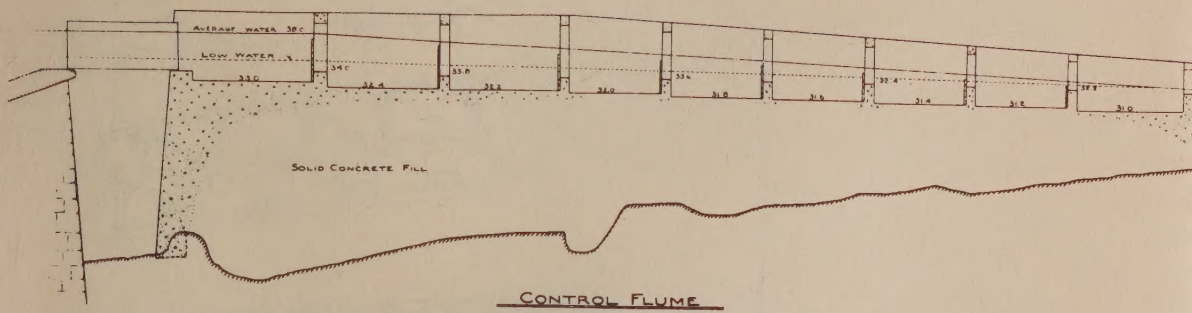
FISHWAY AT ESSEX COMPANY DAM, LAWRENCE, MASS.

River	Merrimack
Distance from Sea	18 miles
Elevation Crest of Dam	34.1 ft. (above mean sea level)
Flashboards	4 ft.
Average Elevation of Forebay	38.0 ft. (above mean sea level)
Minimum Tailwater Elevation	7.0 ft. (above mean sea level)
Maximum Tailwater Elevation	18 ft. (above mean sea level)
Number of Pools	47
Size of Pools	8 ft. x 8 ft.
Average Depth in Pool	4.1 ft.
Drop between Pools	0.6 ft.
Type of Weir	Notched - width of notch top - 2 ft. " " " bottom - 1 ft. depth of notch - 1 ft. floor - - - - sloped. bevel (downstream edges) - 2 in.
Thickness of Weir	1 ft.
Maximum Water Velocity over Weir	5.6 ft/sec.
Water Volume	Approx. 10 cubic feet per second.
Entrance	4 ft. wide, rounded, weir flooded when shad enter, no "jump" at entrance.

Tailwater (above mean sea level)	Velocity through Entrance (ft/sec.)
(Probable minimum water level when shad enter) 11.0	2.6
11.5	1.7
12.5	1.0
(Probable maximum water level when shad enter) 13.5	0.6
14.5	0.3

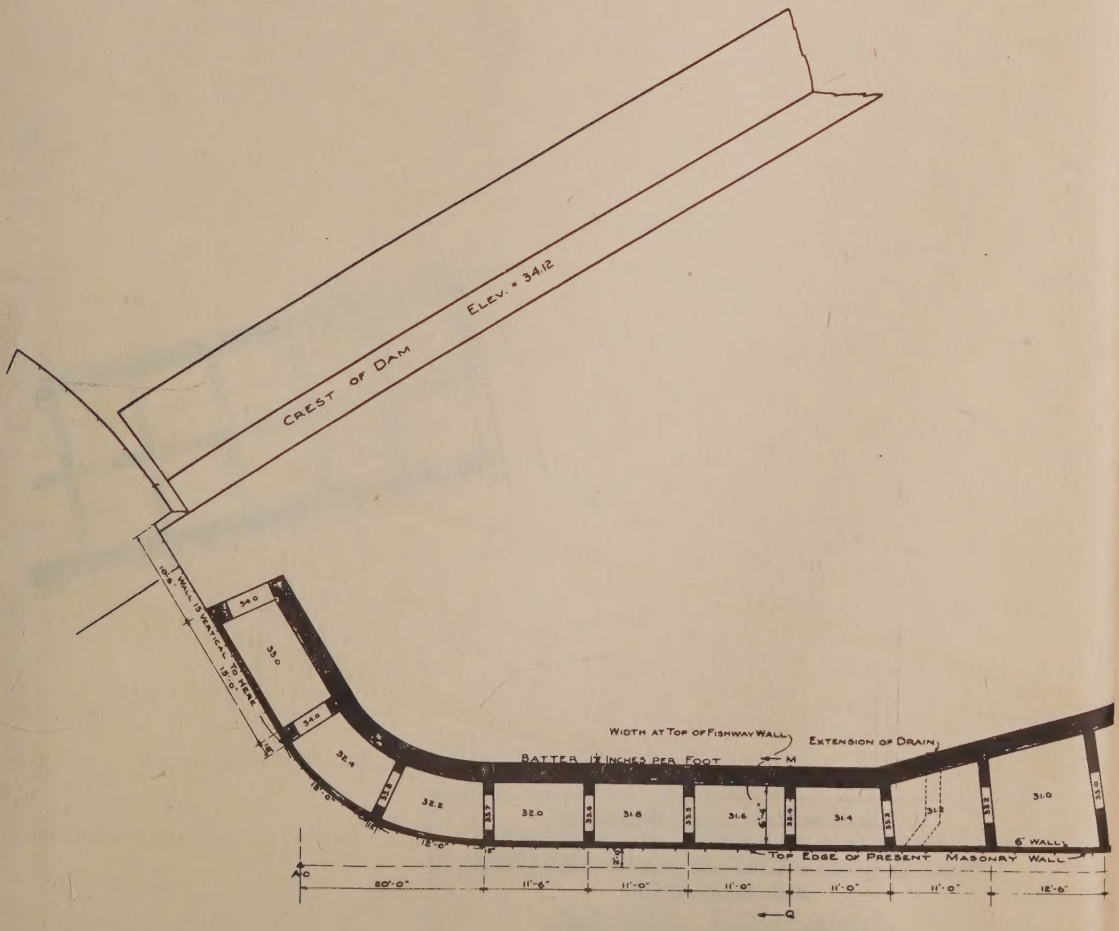
Estimated Number of Shad ascending annually . . . . . 1,500 to 3,000.

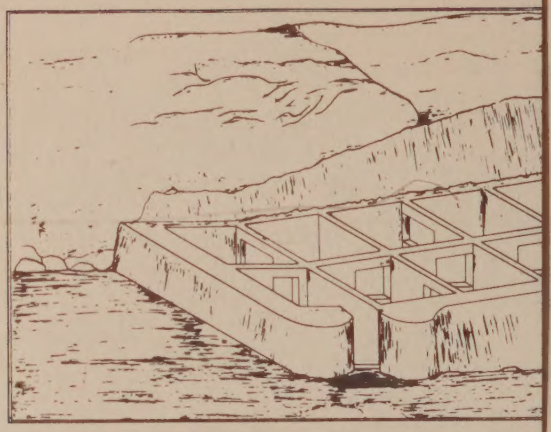
Remarks: . . . . Flow in fishway is characterized by low velocities and a low degree of turbulence.



CONTROL FLUME

SECTION SHOWING FLASH-BOARD METHOD OF REGULATING FLOW IN FISHWAY





SKETCH OF LOWE

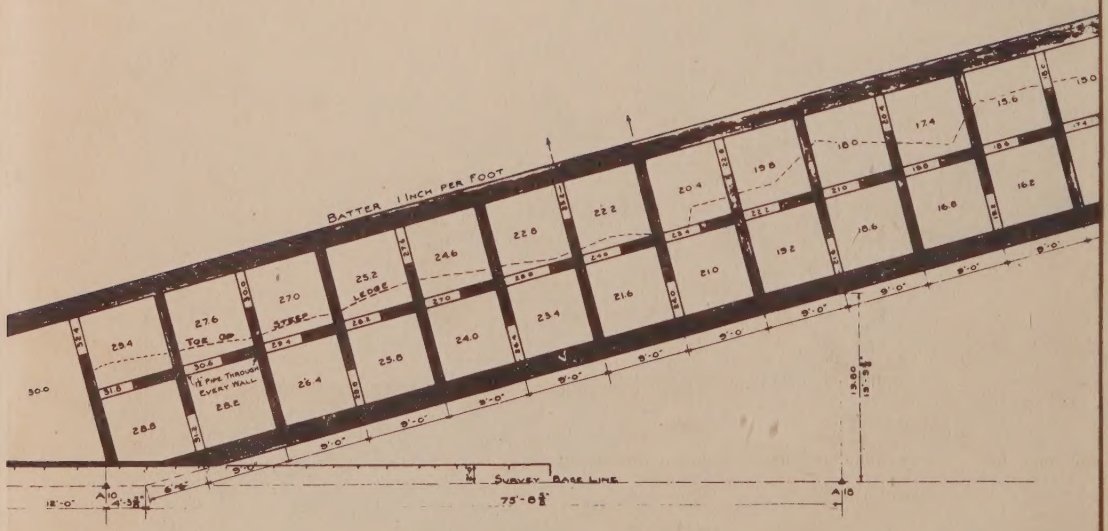
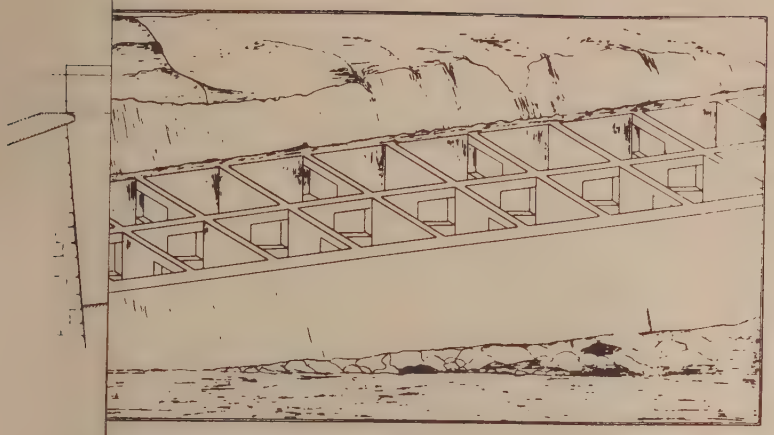
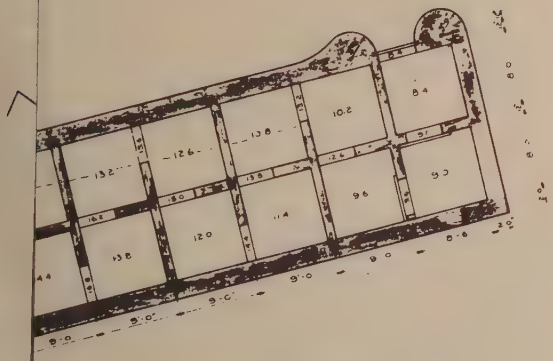


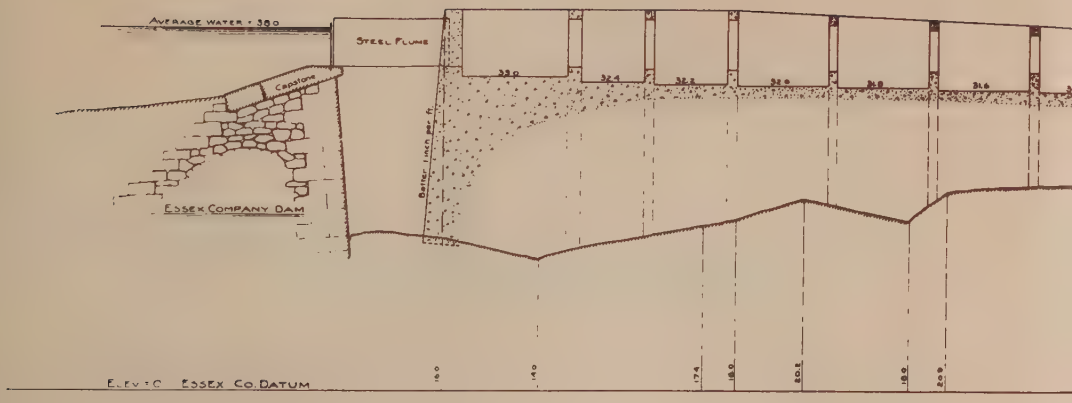
Figure 1. -- Plan of Lawrence Fishway
Note that original weirs were 4 feet in width.
(Modified in 1937).

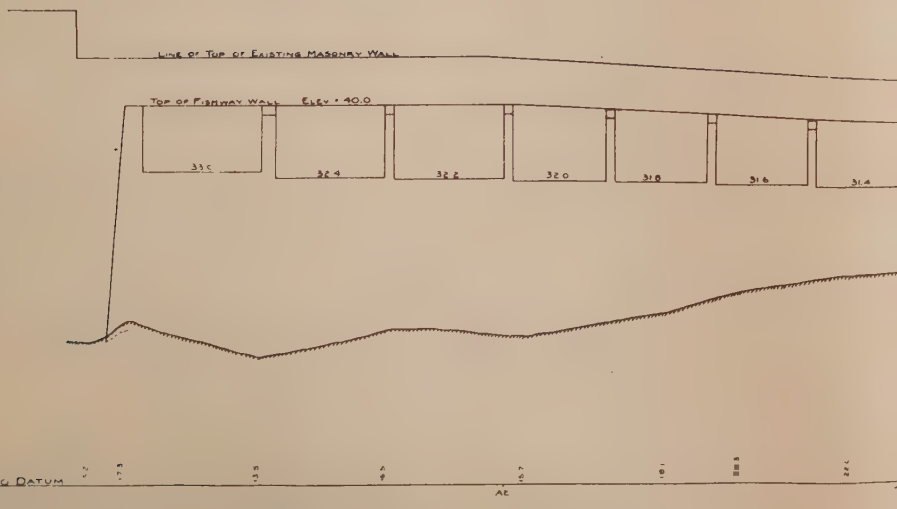


R END OF FISHWAY

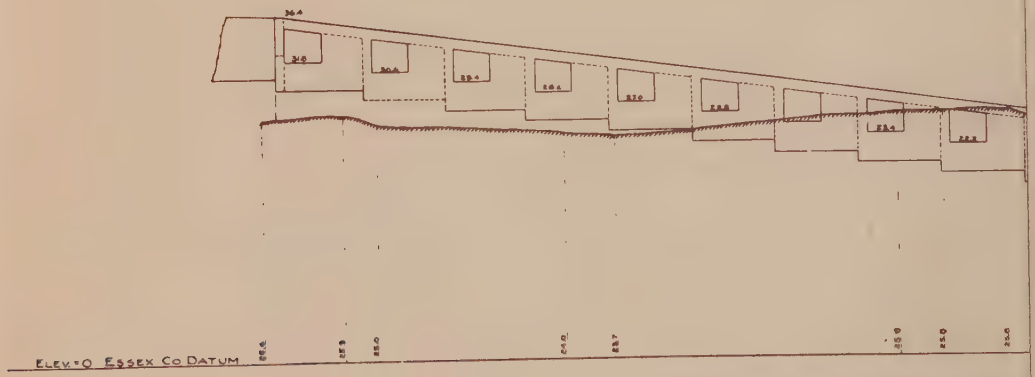


COMMONWEALTH OF MASSACHUSETTS
COMMISSION ON FISHERIES AND GAME.
GENERAL PLAN OF PROPOSED FISHWAY
AT DAM OF THE
ESSEX COMPANY
LAWRENCE, MASS.
SCALE 1 INCH = 8 FEET. NOVEMBER 30, 1918.
R. L. ORING HAYWARD. CIVIL ENGINEER TAUNTON, MASS.

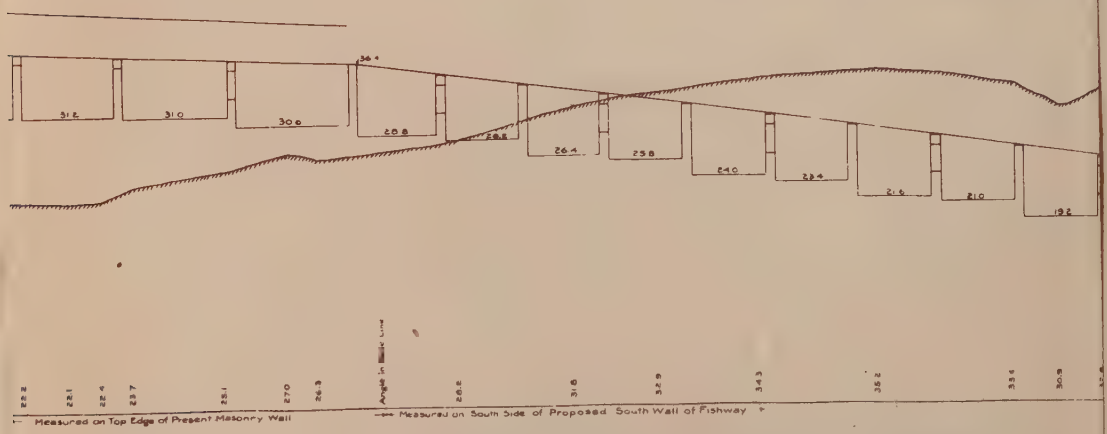

AVERAGE WATER = 380
STEEL FLUME
Capstone
ESSEX COMPANY DAM
Batter 1 inch per ft
33.0
32.4
32.2
32.0
31.8
31.6
E. Ev = 0 ESSEX CO. DATUM
140
140
174
180
80.2
180
209


LINE OF TOP OF EXISTING MASONRY WALL
TOP OF FISHWAY WALL ELEV = 40.0
33.2
32.4
32.2
32.0
31.8
31.6
31.4
ESSEX CO DATUM
AE

PROFILE OF NORTH WALL OF FISHWAY



SECTION ON CENTER WALL



PROFILE OF SOUTH WALL OF FISHWAY

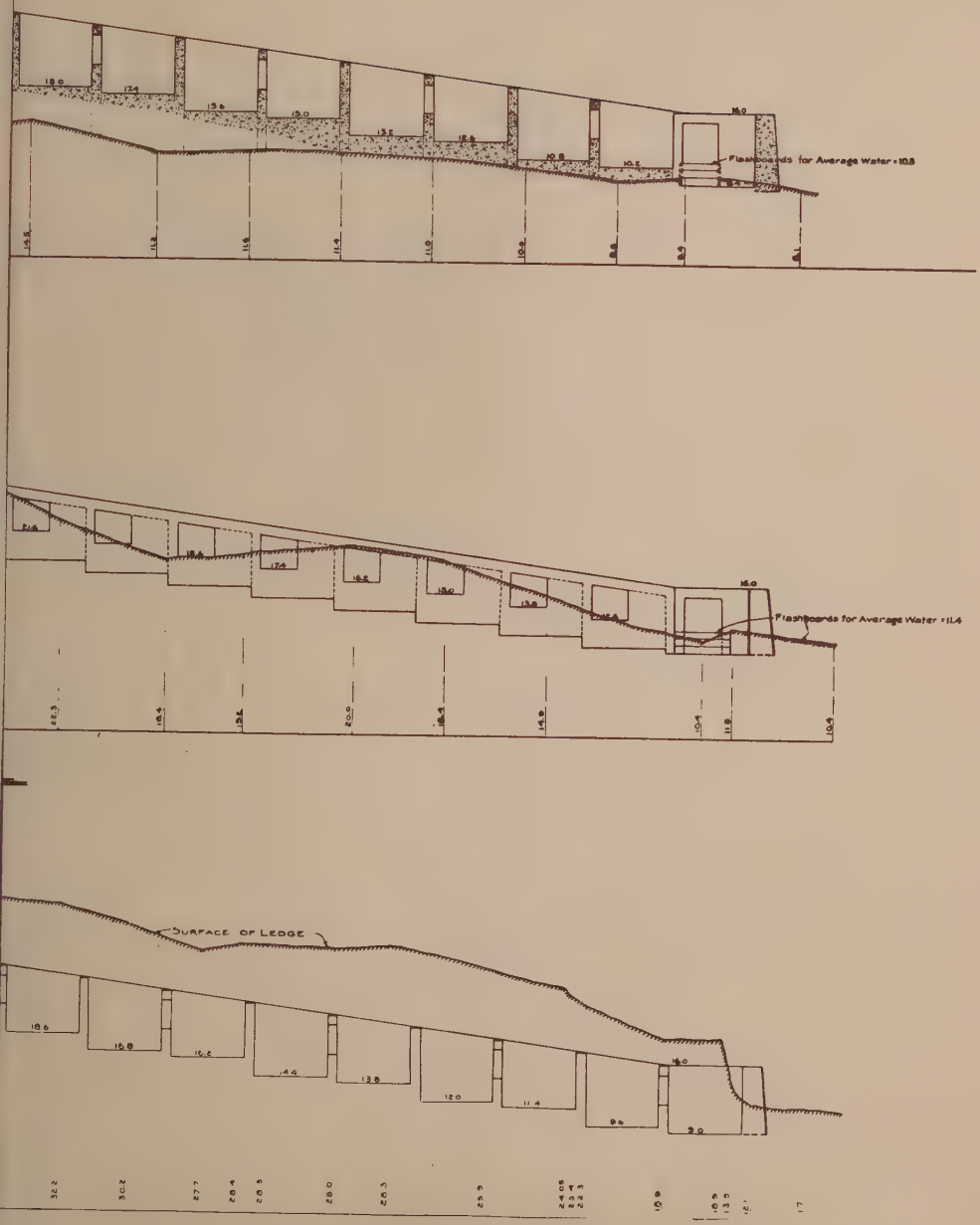
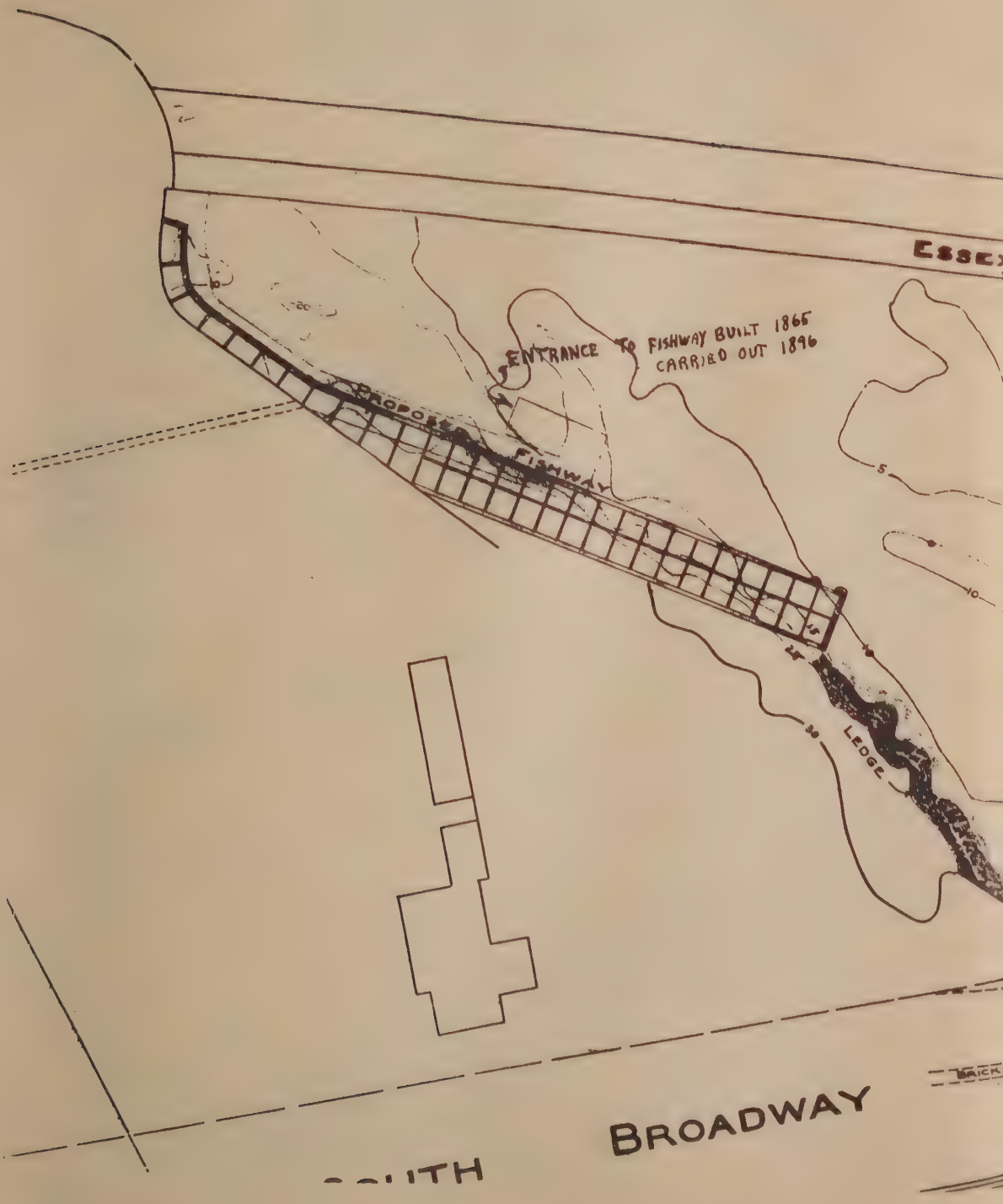


Figure 2. -- Profile of Lawrence Fishway
Note lower flashboards. These proved difficult to maintain. (Modified in 1937).


ENTRANCE TO FISHWAY BUILT 1865
CARRIED OUT 1896
PROPOSED FISHWAY
LEDGE
BROADWAY

MERRIMACK
COMPANY
SEWER

Figure 3. -- Location of Lawrence Fishway
Note relation of fishway entrance to river channel and to shore. Note relation of entrance of unsuccessful previous fishway, built in 1865, to shallow turbulent area (see Figures 4, 6, 10). Note also relation between sewer and entrance of unsuccessful previous fishway built 1897.

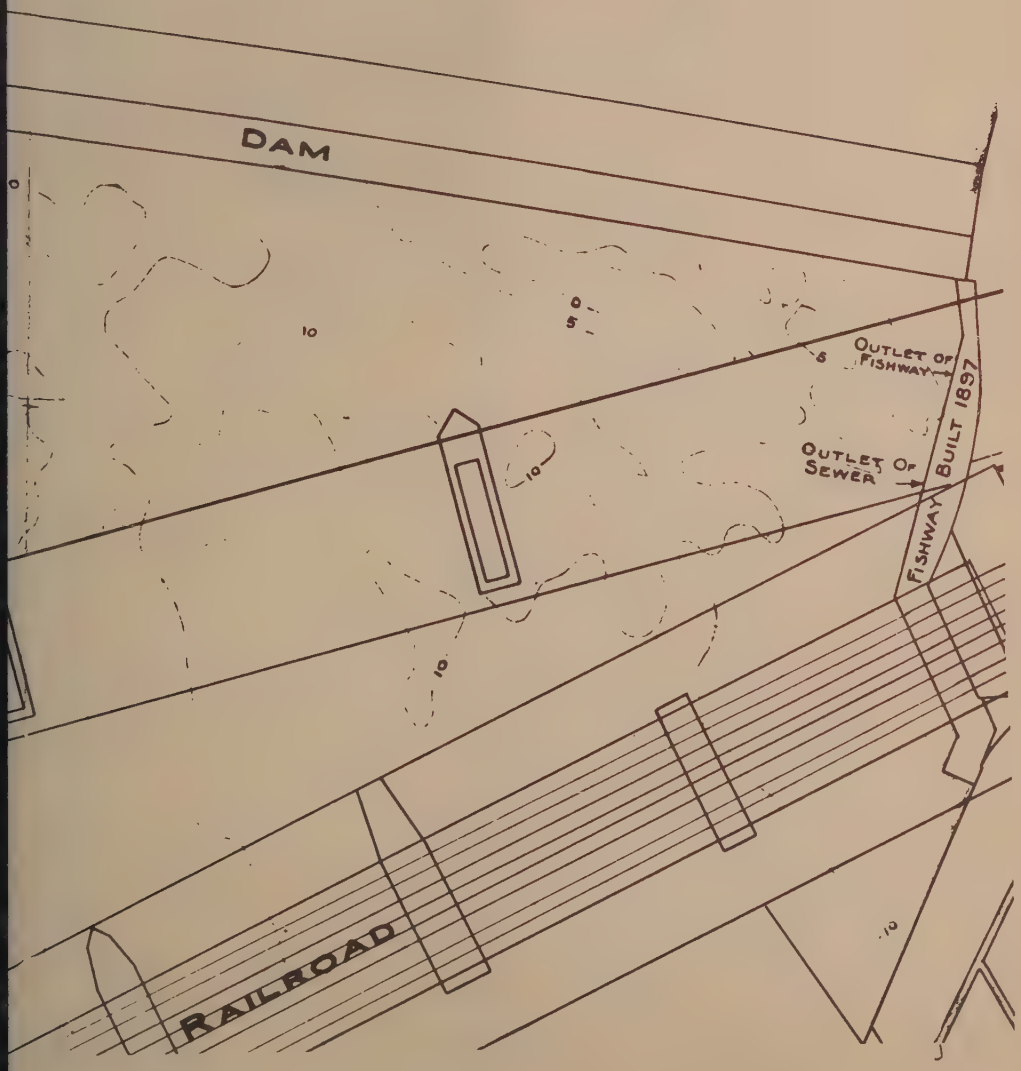


Figure 4.-- General View of Lawrence Fishway
Tailwater Elevation 14.5 ft. (above mean sea level). This water level probably represents the maximum tailwater level under which shad enter the ladder. Water velocity through fishway entrance about 0.3 ft/sec. Note opening (3 ft. x 3 ft.) cut in side by second pool in 1937. There is no evidence of this opening ever being used.

Figure 5.-- Water Conditions at Fishway Entrance
Tailwater Elevation 14.5 ft. (above mean sea level). Note the large rock in the left foreground. The extreme turbulence of the water to the left of this rock can be seen in Figure 4 above.

Figure 6.-- General View of Lawrence Fishway
Tailwater Elevation 17 ft. (above mean sea level) Note extreme turbulence. Shad do not approach the fishway under these water conditions.

Figure 7.-- Flooded Fishway Entrance
Tailwater Elevation 17 ft. (above mean sea level).

Figure 8.-- General View of Lawrence Fishway
Tailwater Elevation 7 ft. (above mean sea level) No water over spillway. Shad are unable to reach the fishway under these conditions.

Figure 9.-- Close-up of Fishway Entrance
Tailwater Elevation 7 ft. (above mean sea level)

Figure 10. -- View of Lawrence Fishway Facing Downstream Tailwater Elevation 17 ft. (above mean sea leavel).

Figure 11. -- Notched Weir.
Note the unusual thickness of the weir and the sloping floor of the notch. The downstream edges of the notch have a 2-inch bevel.

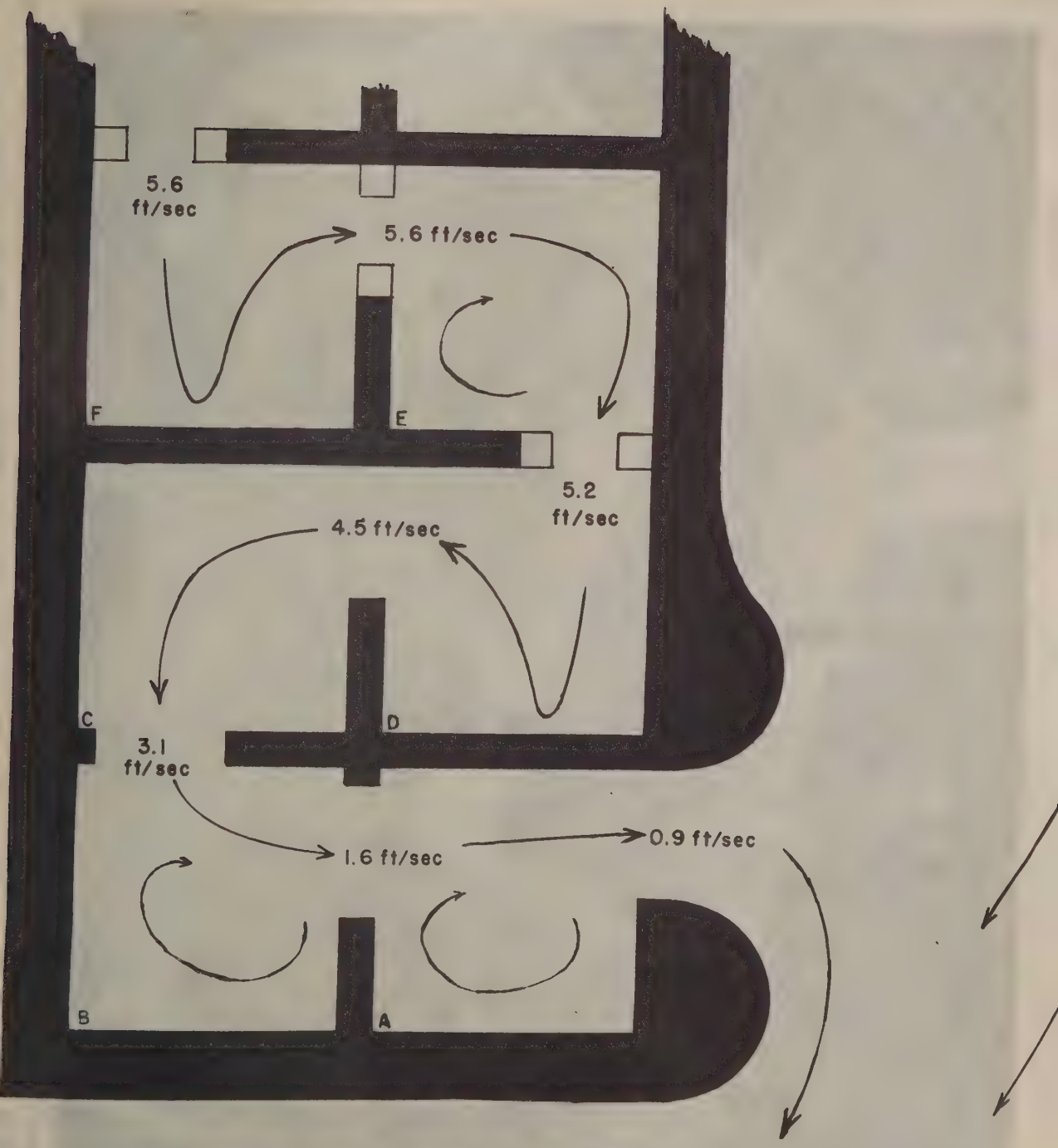


Figure 12.--Diagram of Flow Pattern in Lawrence Fishway
Tailwater Elevation 13 ft. (above mean sea level). The velocities shown are the maximum velocities in the jet. These velocities exist for only a few inches since the jet dissipates rapidly. In pools E and F all velocities, other than in the jet, were less than 1.5 ft/sec. The arrows diagram the main flow, not surface currents. Note that the first 4 weirs are flooded. The almost 180° change in the direction of flow shown in pools D and F is an undesirable feature. It has been observed that the fish sometimes hit the wall at the turning point. Probably the low water velocities involved keep this from being a serious condition in the Lawrence Fishway.

Figure 13. - General View of Fishway Model - (Alden Hydraulic Laboratory)
Tailwater Elevation 13ft. (Above mean sea level) The optimum conditions for entrance of shad into the fishway are probably at this water level. Note area of reduced velocities at fishway entrance (black dye).

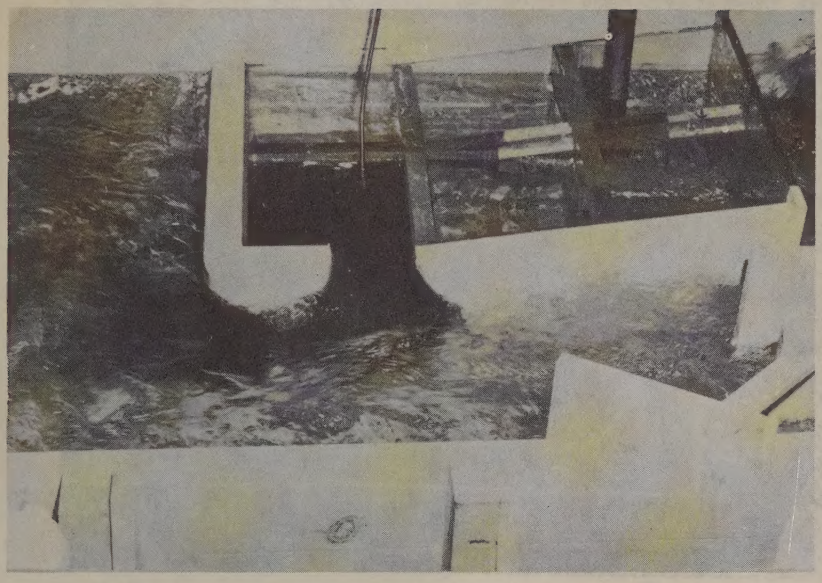


Figure 14.-- Entrance to Fishway (Model)
Tailwater Elevation 15 ft. (above mean sea level) Note flooding of weirs.

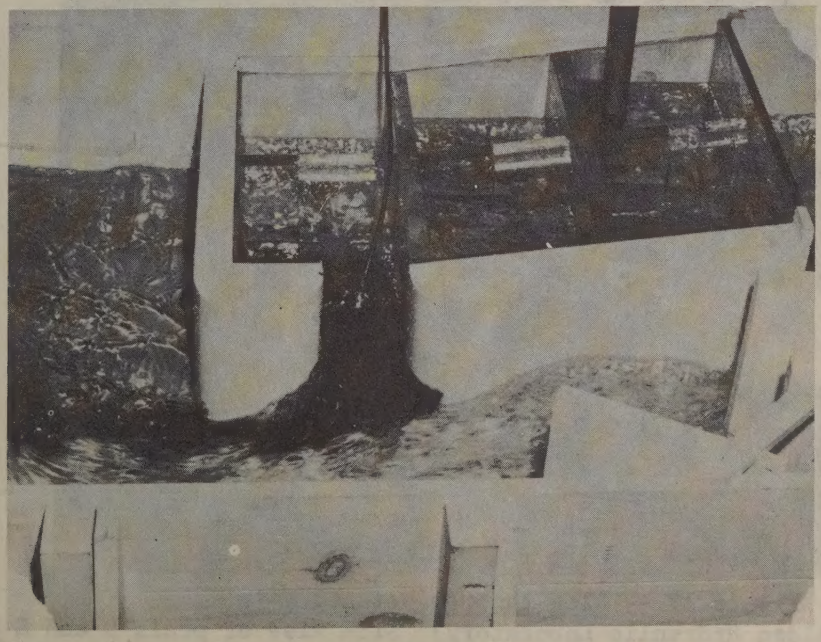


Figure 15.-- Entrance to Fishway (Model)
Tailwater Elevation 11 ft. (above mean sea level) This water level is probably close to the minimum tailwater level for entrance of shad into the fishway. Note that the first weir is flooded.

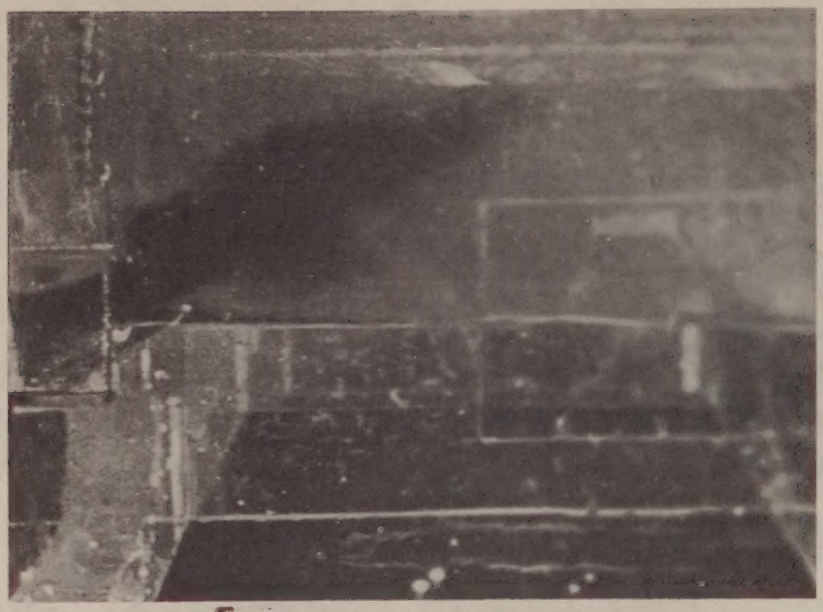


Figure 16.-- Jet from Notched Weir
(Model - Alden Hydraulic Laboratory) End view of pool E (see diagram Figure 12) of model.

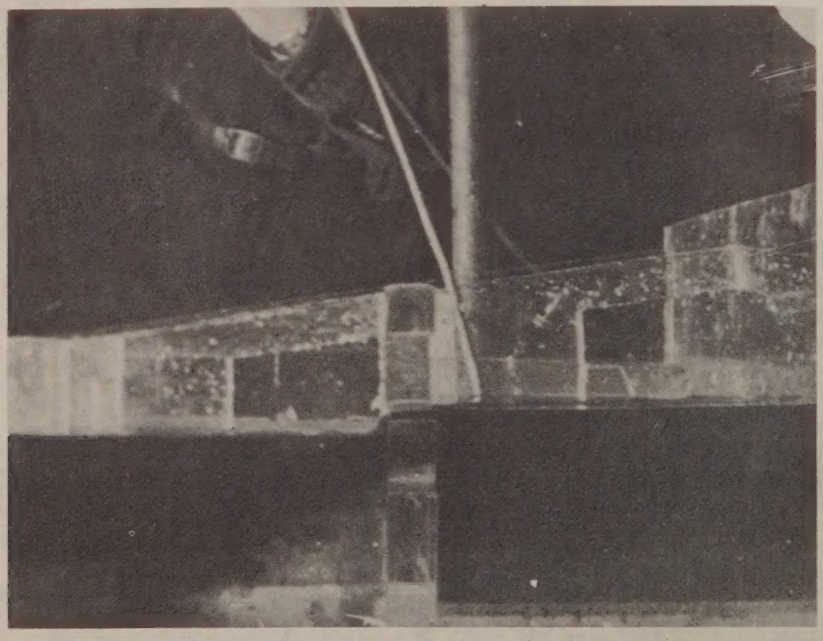


Figure 17.-- Flow through Notched Weir
(Model - Alden Hydraulic Laboratory) Side view of pools D and E (see diagram Figure 12) of model. Note that fish can swim from one pool to another (no "jump" necessary). Note also rapid divergence of jet.

Interior--Duplicating Section--Washington,D.C.
2903